# PLANS FOR REGULATION OF LEVELS OF LAKE ERIE

Hydraulic Model Investigation

TECHNICAL REPORT NO. 2-456

June 1957

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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PREFACE

The model study of plans for the regulation of levels of Lake Erie was initiated by the U. S. Army Engineer District, Buffalo, and was authorized by the Chief of Engineers in the 2d indorsement, dated 26 January 1954, to a letter from the District Engineer, dated 11 January 1954. The study was conducted at the Waterways Experiment Station during the period February-July 1954.

During the course of the study several conferences were held for the purpose of formulating the testing program and reviewing the test results. At these conferences Mr. H. G. Dewey represented the North Central Division, Messrs. S. B. Hunt and J. G. Weinrub the Buffalo District, and Messrs. L. D. Kirshner and L. W. Townsend the U. S. Lake Survey.

Engineers of the Waterways Experiment Station concerned with the model study were Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division; Mr. G. B. Fenwick, Chief of the Rivers and Harbors Branch; Mr. E. B. Lipscomb, Chief of the Potamology Section; and Mr. E. E. Moorhead, in immediate charge of the model. This report was prepared by Mr. Lipscomb.

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# SUMMARY

Because of the effects of fluctuations in water levels of the Great Lakes on economic interests, consideration is being given to engineering works to regulate these levels. The surplus water of Lake Erie is funneled through the Niagara River, the link between Lakes Erie and Ontario, and thus the capacity of the river controls flow from, and heights of, Lake Erie. The purpose of the model study was to determine the nature and extent of excavation in the Niagara River required to increase the capacity of the river at times of high lake levels, the best location for a regulating structure extending completely across the river channel, and the length of regulating structure that would have to be closed to reduce flow into the river during periods of low lake levels.

The hydraulic investigation was conducted on an existing model used to study the development of power and preservation of the scenic spectacle at Niagara Falls. The model was of the fixed-bed type, constructed to linear scale ratios of 1:360 horizontally and 1:60 vertically, and reproduced 26 miles of the Niagara River from Lake Erie to the Falls.

Two excavation plans were investigated: one based on a wide, shallow channel and the other on a deep, narrow channel. Test results indicated that either plan would produce substantial lowering of lake levels through excavation of up to about 10,000,000 cu yd; greater amounts of excavation would produce only slight additional lowerings. Of the two plans, the deep, narrow design was found more efficient.

Two locations of the regulating structure were studied: one at Bird Island about 4000 ft upstream from Peace Bridge, and the other about 700 ft downstream from Peace Bridge. At each location tests were made of the structure closing from both the American and Canadian sides. Test results showed that at Bird Island a shorter length of structure would be required to be closed on the American side than on the Canadian side; downstream from the Peace Bridge the reverse was true.

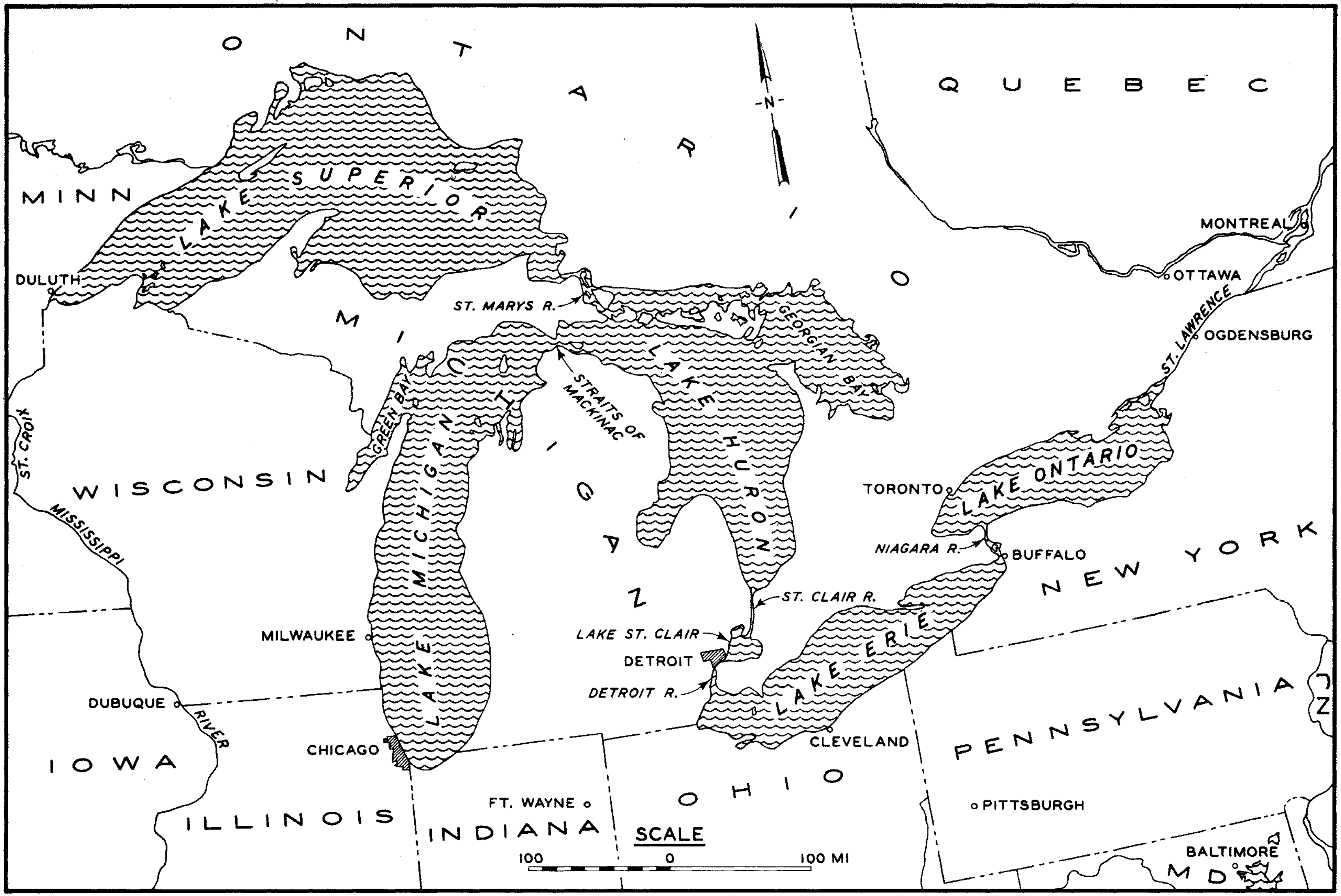


Fig. 1. The Great Lakes system

# PLANS FOR REGULATION OF LEVELS OF LAKE ERIE

## Hydraulic Model Investigation

## PART I: INTRODUCTION

### The Prototype*

#### The Great Lakes

1. The Great Lakes system comprises five great bodies of fresh water -- Lakes Superior, Huron, Michigan, Erie, and Ontario -- and their connecting channels which form a chain that extends halfway across the North American continent (fig. 1). These lakes and their tributaries above Ogdensburg, N. Y., drain an area of approximately 298,000 square miles and constitute the major portion of the St. Lawrence Basin. The Great Lakes and their connecting channels have a total water-surface area of about 95,000 square miles, of which about 60,950 square miles are in the United States.

2. The connecting channels of the Great Lakes, because of their generally limited capacities, influence to some extent the elevations of the lakes. St. Marys River, which connects Lake Superior and Lake Huron, descends about 22 ft in its 70-mile length with most of the drop occurring at St. Marys Falls. Lakes Huron and Michigan are connected by such a wide channel (Straits of Mackinac) that they are in effect one lake and their surfaces are at the same elevation. The outlet of Lake Huron is through the St. Clair River, Lake St. Clair, and the Detroit River to Lake Erie, a distance of about 87 miles with a total fall of 8 ft. The Niagara River, which connects Lakes Erie and Ontario, is 36 miles in length and has a fall of 326 ft. The outlet of Lake Ontario is the St. Lawrence River.

3. The Great Lakes are nontidal. Levels fluctuate from year to year and from month to month during each year. The difference between

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* Information obtained from U. S. Senate Document No. 11, 84th Congress, 1st Session.

the highest and lowest monthly average level on each of the lakes since 1860, the period of record, has amounted to from 4 to more than 6 ft. The seasonal variation on each lake usually ranges between 1 and 2 ft with the seasonal low occurring in the winter and the high in the summer months. In addition to the long-range and seasonal fluctuations, daily and hourly stage fluctuations vary from a few inches to several feet according to the lake and place involved. Such fluctuations are usually produced by variations in barometric pressure and by winds, or the levels may be affected by seasonal weed growths in the connecting rivers.

Lake Erie

4. Lake Erie is the shallowest of all the Great Lakes and is considerably smaller than the three lakes above it. Its greatest depth is only 210 ft as compared to maximum recorded depths of 1302 ft, 923 ft, and 750 ft for Lakes Superior, Michigan, and Huron, respectively. The Niagara River (fig. 2) carries the surplus water of the upper Great Lakes seaward from Lake Erie to Lake Ontario. Its flow varies with the level of Lake Erie, a rock ledge at the lake outlet at Buffalo acting as a submerged weir. Owing to the large area of the watershed and the immense storage capacity of the upper lakes, flow of the Niagara River is more uniform than that of most streams, averaging about 200,000 cfs.

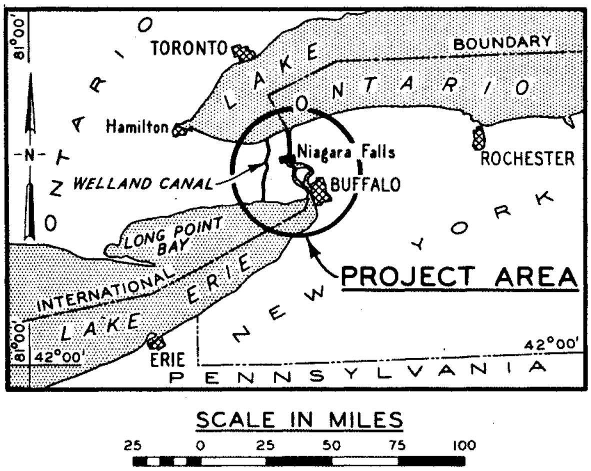



Fig. 2. Location map

## The Problem

5. The long-term and seasonal fluctuations of levels of the water surfaces of the Great Lakes have varying effects on three major economic interests -- shore property, lake shipping, and hydroelectric power generation. In general, high lake levels benefit shipping and power.

Increased depths in harbors and channels, which permit vessels to load even an inch or two deeper, result in sizeable increases in cargoes. Hydroelectric power production is obviously benefited by higher heads and an abundance of water. On the other hand, high lake levels are extremely injurious to shore properties, particularly during storms.

6. There is no way to solve these problems as long as the lakes are in their present unregulated state, since the recurring highs and lows are natural and not man-made. Therefore consideration is being given to the feasibility of engineering works that would regulate the levels of the lakes to the mutual benefit of the three interests affected.

## Scope and Purpose of the Model Study

7. This model study was concerned only with plans for regulating the levels of Lake Erie. The primary purpose of the study was to determine the nature and extent of excavation in the Niagara River that would be required to increase the capacity of the river at times when high Lake Erie levels would otherwise exist. Of secondary importance in the study was the determination of the location and closed length of a regulating structure that would control flow into the river and thus maintain higher lake levels during periods of normal low levels.

# PART II: THE MODEL

8. The hydraulic investigation of regulation of levels of Lake Erie was conducted on an existing model used previously to study the development of power and the preservation and enhancement of the scenic spectacle at Niagara Falls. This model is described in detail in Waterways Experiment Station Technical Memorandum No. 2-411, Preservation and Enhancement of Niagara Falls, dated July 1955, and only features particularly pertinent to this investigation are included here.

## Description

9. The prototype area reproduced in the Niagara River model is shown on plate 1 and fig. 3, and included the river from approximately 11,500 ft above the Peace Bridge at Buffalo to Rainbow Bridge, as well as all significant topographic features. The upper limits of the model extended far enough into Lake Erie to assure accurate reproduction of flow entering the Niagara River from the lake. The model was of the fixed-bed type with all channel and overbank areas molded in concrete.

## Scale Ratios

10. The model was constructed to linear scale ratios, model:prototype, of 1:360 horizontally and 1:60 vertically with a geometrically resultant slope scale of 6 to 1. Selection of these scale ratios was based on the following considerations: (a) previous experience with similar problems indicated such a model would furnish satisfactory solutions of the problems presented, and would be considerably more economical to construct than an undistorted model; and (b) known physical and hydraulic characteristics of the Niagara River indicated such a model would accurately reproduce the proper roughness factors and hydraulic characteristics of the prototype without appreciable alteration of the model channels. Other scale ratios, model:prototype, established in accordance with the Froudian relationship, were: velocity, 1:7.74; discharge, 1:167,328; time, 1:46.48.

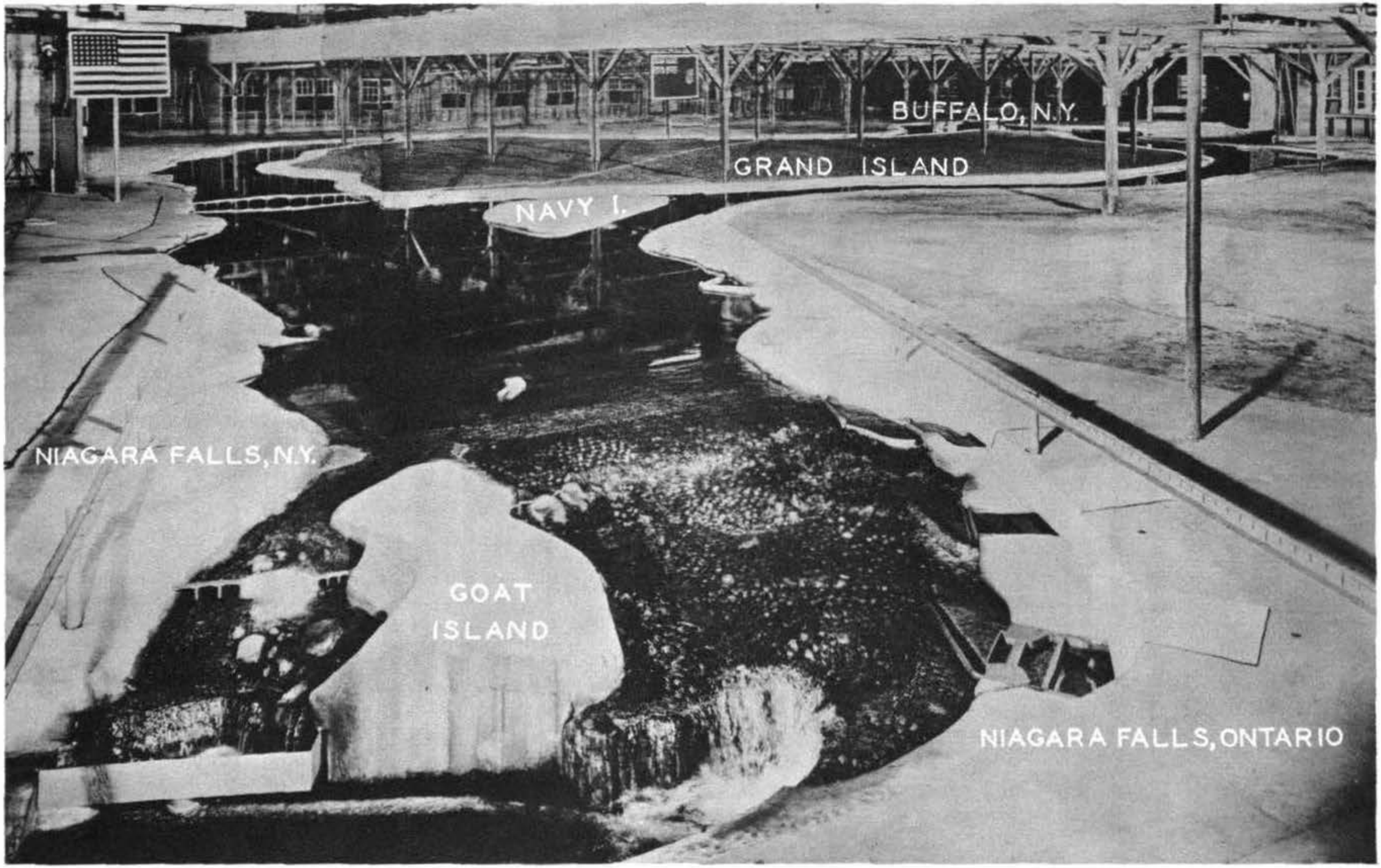



Fig. 3. Niagara River and Falls model

## Model Appurtenances

11. The bridges and existing and proposed power intakes along the river were precisely located in the model. The intakes were constructed of wood and the bridges of wood piers and sheet-metal trusses, as shown on fig. 4. Flow into the intakes was controlled by standard gate valves

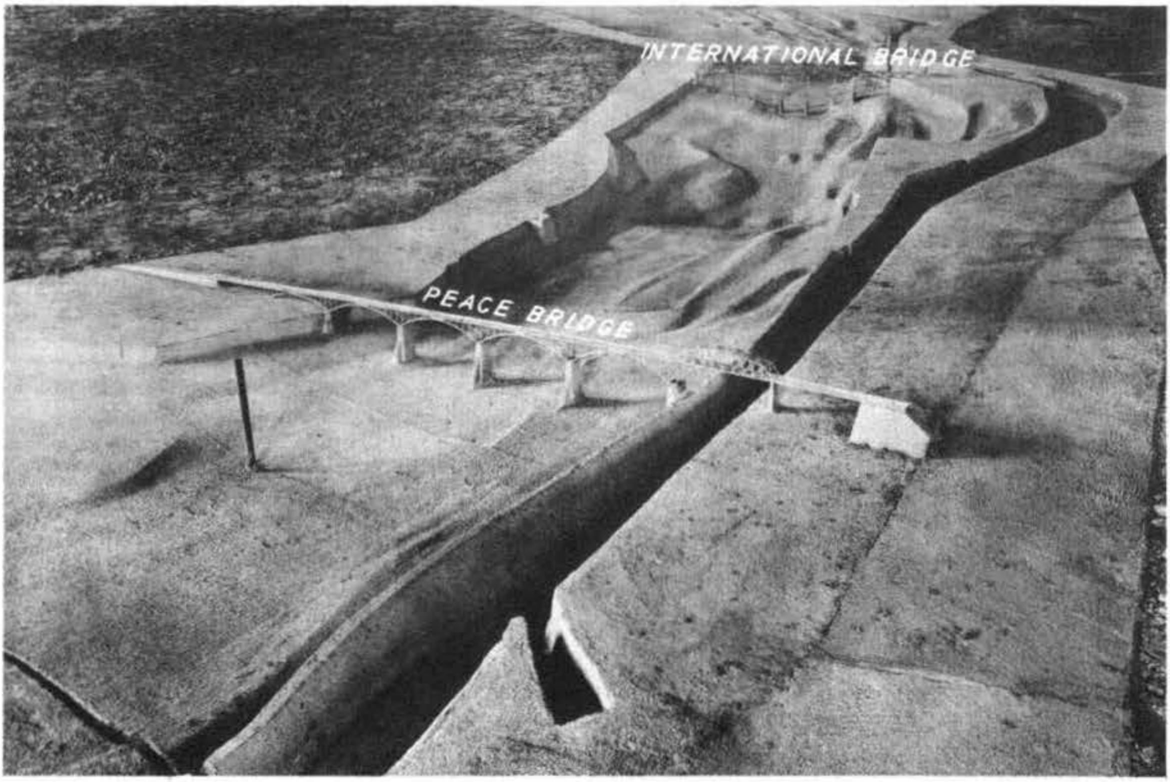



Fig. 4. Close-up of model showing type of construction used to reproduce channel, overbank areas, and bridges

and measured by Van Leer weirs. Means were also available for measurement of the flow in the channels around Grand Island and the flow over the American and Horseshoe Falls. Water-surface elevations in special problem areas were measured by means of portable point gages.

# PART III: VERIFICATION OF THE MODEL

## Procedure

12. The "verification" of this type of hydraulic model is accomplished by careful adjustment of channel roughness until an accurate and detailed reproduction of all observed hydraulic phenomena of the prototype river is obtained. The results obtained at the culmination of this hydraulic adjustment phase demonstrate the degree of accuracy and reliability that can be expected from tests of proposed plans of improvement. Verification of the Niagara River and Falls model fell naturally into two separate operations: first, verification of the relatively low-velocity channel upstream from the Cascades, including verification of the distribution of flow around Grand and Goat Islands; and second, verification of the relatively high-velocity Cascades and Falls section. However, since the study of lake regulation involved only that portion of the model between the Cascades and Lake Erie, description of the verification of the Cascades and Falls section will be omitted from this report. The only change in the original model verification was concerned with a special adjustment of the Buffalo and Black Rock water-surface elevation gages. A description of the model verification and special adjustment is presented in the following paragraphs.

## Verification of River above Cascades

13. The first step in the verification of the model was to adjust the roughness in the section of the river above the Cascades until the water-surface elevations at 18 gages, located as shown on plate 2, agreed with simultaneous readings made in the prototype at these gage locations on 25 April and 2 May 1951. The prototype observations were made at a time when there was very little fluctuation in river levels and discharge (223,488 cfs) and during the season of the year when the river was not yet affected by the seasonal weed cycle.

14. Results of the verification tests of this reach of the river

are presented on plate 3. Examination of this plate shows that the model water-surface elevations checked the observed prototype elevations within 0.1 to 0.2 ft at all gages. Such agreement was considered to be satisfactory.

## Special Adjustment

15. Since the Buffalo gage reflects the levels of Lake Erie and the Black Rock gage reflects the tailwater conditions below the rock ledge at Buffalo, it was felt that special care should be given to the adjustment of these two gages. Accordingly, these gages were adjusted to data based on the following stage-discharge relation formulae derived by the U. S. Lake Survey from flow measurements representing present river regimen and diversion conditions:

$$Q = 1954\ (B - 556.73)^{1.5}\ (B - BR)^{0.3}$$
$$Q = 1730\ (BR - 550.25)^{1.5}\ (BR - CI)^{0.4}$$

where: B is Buffalo stage

BR is Black Rock stage

CI is Conners Island stage

16. The data derived from these stage-discharge relationship formulae are as follows:

| Total River Flow in 1000 cfs | Stage in Feet 1935 Datum | | |
|---|---|---|---|
| | Buffalo | Black Rock | Conners Island |
| 120 | 568.26 | 563.78 | 561.48 |
| 130 | 568.83 | 564.23 | 561.75 |
| 140 | 569.38 | 564.68 | 562.02 |
| 150 | 569.93 | 565.12 | 562.31 |
| 160 | 570.46 | 565.56 | 563.60 |
| 170 | 570.97 | 566.01 | 562.92 |
| 180 | 571.48 | 566.43 | 563.20 |
| 190 | 571.98 | 566.86 | 563.51 |
| 200 | 572.47 | 567.28 | 563.81 |
| 210 | 572.96 | 567.71 | 564.13 |
| 220 | 573.43 | 568.12 | 564.45 |
| 230 | 573.90 | 568.54 | 564.77 |
| 240 | 574.36 | 568.95 | 565.09 |
| 250 | 574.81 | 569.36 | 565.42 |
| 260 | 575.26 | 569.76 | 565.74 |

17. Results of the adjustment of the model to the above data are presented in the form of stage-discharge relationships (for both model and prototype) at the Buffalo and Black Rock gages on plates 4 and 5, respectively, and in the form of stage relationships between the Buffalo and Black Rock gages on plate 6. Examination of these plates shows satisfactory agreement between the prototype and model for the middle range of flows, with model stages being slightly high at the low flows and about 0.2 ft low at the high flows. It was felt that these slight differences would not significantly affect the results of the tests.

## PART IV: TESTS AND RESULTS

18. The test program was divided into two separate but interrelated phases. The first phase was concerned with the determination of the nature and amount of excavation required to increase the outlet capacity of the Niagara River so as to carry certain specified regulated flows at specified lake levels. The second phase was concerned with determination of the lengths and location of regulating structures required to maintain certain specified lake levels under minimum and average flow conditions.

### Tests of Excavation Plans

#### Description of tests and procedure

19. The plans of excavation tested were located within a section of the river about 1500 ft wide extending from about one mile above the Peace Bridge to about one-half mile below the International Bridge. No excavation extended below elevation 520 or closer than 50 ft to piers or shore lines along the U. S. and Canadian banks. Seventy-foot-wide islands were left unexcavated around the Peace Bridge piers, and new piers 40 ft wide were installed where excavations were made through the International Bridge. Two types of channels were investigated: a wide-shallow type in which the full 1500-ft width of channel was maintained while the depth was varied; and a deep-narrow type in which the bottom elevation was maintained at the maximum dredging depth (el 520) and the width was varied. The testing of each of these two types of channel involved progressive reductions in the hydraulic capacity of the channel through progressive decreases in either the depth of the wide-shallow channel or the width of the deep-narrow channel. In tests of both types of channel, a regulating structure for the control of low lake levels was simulated at the head of the river and across its entire width by a series of 10-ft-wide piers with 100-ft-wide openings between piers. However, no gates were simulated in these tests since they were concerned with reducing high lake levels and at such times all gates would be open.

20. Each excavation plan was tested for flows of 150,000 cfs; 200,000 cfs to 220,000 cfs, inclusive, in increments of 10,000 cfs; and 255,000 cfs. Water-surface elevations were observed at the Buffalo, Peace Bridge, Black Rock, and Conners Island gages. Water-surface elevations at the Conners Island gage were controlled to reflect the existing stage relationship between the Conners Island gage and the Buffalo gage (plate 7). Flow over the Falls was maintained at 100,000 cfs, the amount required to preserve the beauty of the spectacle. During the course of the study it was found that under certain conditions it would not be possible to hold Conners Island stages in their present relationship to the Buffalo stage as specified and still maintain the 100,000 cfs flow over the Falls; when this situation arose in the tests, departure was made from the stage relationship as necessary to pass the required 100,000 cfs over the Falls.

21. It was assumed for the purpose of this study that the roughness (Manning's "n") of the excavated channel would be of the same order of magnitude as that of the natural channel.

Preliminary tests

22. In preliminary tests of the excavation plans it was established that excavation downstream of a point about 1000 ft above the International Bridge would have no material effect on lowering lake levels. It was also established that, owing to the relatively shallow depths in the lake, a fan-shaped entrance to the excavated channel would be needed to draw the required flow from the lake without excessive loss of head. Accordingly, these two features were taken into consideration in the design of all excavation plans.

Wide-shallow design

23. Plans of excavation for the wide-shallow design are shown on plate 8. The plan for test 1 consisted of a 1500-ft-wide channel excavated to the maximum dredging depth at elevation 520. In the seven succeeding tests, the same width was maintained but the depth of dredging was reduced in progressive steps.

24. Results of the tests of the wide-shallow excavation plans are presented in table 1 and on plates 9 and 10. The water-surface elevations

for each test at the gages and for the discharges mentioned in paragraph 20 are listed in table 1. On plate 9 water-surface elevations at the Buffalo gage are plotted against outflow from Lake Erie for the eight excavation plans tested together with the model-prototype relationships for natural-river conditions. On plate 10 are plotted, for each test flow, the relationship between water-surface elevations at the Buffalo gage and the volumes of excavation required to produce a given elevation at Buffalo. These plots show that substantial lowerings of water-surface elevations were produced at the Buffalo gage for volumes of excavation up to about 10,000,000 cu yd; however, when the excavation exceeded that figure only slight additional lowerings were effected. Lake-regulation plan 54-E-11 (North Central Division, CE) provides for a Buffalo stage of 569.6 with river capacities of 200,000 cfs and 220,000 cfs, which correspond to a minimum monthly mean regulated flow of 170,000 cfs. Plan 53-E-10 assumes a Buffalo stage of 568.6 with a river capacity of 200,000 cfs. The data presented on plates 9 and 10 show that the following volumes of excavation would be required to meet the above conditions:

| River capacity cfs | Buffalo Stage ft | Excavation cu yd |
|---|---|---|
| 200,000 | 568.6 | 9,600,000 |
| 200,000 | 569.6 | 5,400,000 |
| 220,000 | 569.6 | 8,000,000 |

Deep-narrow design

25. Plans of excavation for the deep-narrow design are shown on plate 11. In this series of tests the bottom of the excavated channel was maintained at elevation 520 and the width of the channel was 300 ft in test 9, 600 ft in test 10, 900 ft in test 11, and 1500 ft in test 12. The same operational procedure was used in this series of tests as was used in tests of the wide-shallow design.

26. Results of the tests of the deep-narrow excavation plans are presented in table 2 and on plates 12 and 13. The methods of presenting results of these tests are the same as for the wide-shallow excavation plans. Excavation volumes required to satisfy plan 53-E-10 and plan 54-E-11 were as follows:

| River Capacity, cfs | Buffalo Stage, ft | Excavation, cu yd |
|---|---|---|
| 200,000 | 568.6 | 8,200,000 |
| 200,000 | 569.6 | 3,600,000 |
| 220,000 | 569.6 | 6,400,000 |

## Tests of Regulating Structure

27. Two locations for the structure were investigated: one about 4000 ft upstream of Peace Bridge opposite Bird Island, and the other about 700 ft downstream from Peace Bridge (plate 14). At each location the regulating structure extended completely across the river channel and consisted of 100-ft-wide gates separated by 10-ft-wide piers. Each structure was tested in conjunction with the wide-shallow excavation plans of tests 1, 3, and 7. The channels for these plans were 1500 ft wide, with bottom elevations of 520.0, 536.0, and 548.0, respectively. The purpose of the regulating structure tests was to determine the best location for, and the length of structure that would have to be closed to maintain certain lake elevations under specified river flows. Twenty-three test conditions were used involving, in addition to variation in channel bottom elevations, the following river flows and lake elevations:

| River Flow, cfs | Buffalo Stage, ft |
|---|---|
| 90,000 | 571.9 |
| 90,000 | 572.9 |
| 140,000 | 572.9 |
| 200,000 | 569.6 |
| 220,000 | 569.6 |

For a few of the test conditions, comparable tests were run with the structures closed first from the American shore and then from the Canadian shore.

28. Results of the tests of the regulating structure are presented in table 3. The results indicate that at the Bird Island location a much shorter length of the structure would have to be closed from the American shore (test 13, 2504-ft length) than from the Canadian shore (test 16, 3400-ft length). At the Peace Bridge location the shorter closed section would be on the Canadian side, as can be seen by comparing test 20 (Canadian side, 1400-ft length) and test 17 (American side, 1494-ft

length). Raising the bottom of the excavated channel from elevation 520 to elevation 548 had no measurable effect on the length of structure to be closed at the Bird Island location but reduced the length about 178 ft at the Peace Bridge location. A comparison of test 13 and test 21 indicates that for an outflow of 90,000 cfs, with the structure closed from the American side at Bird Island, the length of closed structure would have to be increased 164 ft to change the lake level from elevation 571.9 to elevation 572.9.

## PART V: DISCUSSION OF RESULTS

29. This model investigation is believed to have been sufficiently comprehensive to provide a basis on which a definite plan for regulation of Lake Erie can be formulated. The data are so presented that excavation quantities to meet any specified lake level and river discharge can be readily determined.

30. A comparison of the results of the two types of excavation plans indicates that for volumes of excavation up to about 10,000,000 cu yd the deep-narrow type of channel would be about 20 to 30 per cent more efficient than the wide-shallow type.

31. Tests of locations for the regulating structure indicated that at the Bird Island location a shorter length of the structure would have to be closed on the American side than on the Canadian side to maintain desired lake elevations under specified river flows; the reverse was true at the Peace Bridge location.

Table 1

Test Results, Wide-shallow Excavation Plans

| Outflow from Lake Erie, cfs | Water-surface Elevations in Feet, USLS 1935 Datum | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Prototype | Verification | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 | Test 7 | Test 8 |
| | | | | | Buffalo Gage | | | | | |
| 150,000 | 569.93 | 570.16 | 566.20 | 566.20 | 566.26 | 566.50 | 566.56 | 566.92 | 567.40 | 568.84 |
| 200,000 | 572.47 | 572.50 | 568.00 | 568.18 | 568.30 | 568.48 | 568.60 | 568.96 | 569.44 | 571.12 |
| 210,000 | 572.96 | 572.98 | 568.36 | 568.48 | 568.66 | 568.90 | 569.02 | 569.38 | 569.86 | 571.54 |
| 220,000 | 573.43 | 573.40 | 568.66 | 568.78 | 568.96 | 569.26 | 569.38 | 569.74 | 570.19 | 572.02 |
| 255,000 | 575.26* | 574.96* | 569.80 | 569.92 | 570.10 | 570.52 | 570.76 | 571.00 | 571.60 | 573.46 |
| | | | | | Peace Bridge Gage | | | | | |
| 150,000 | | 567.10 | 565.42 | 565.42 | 565.36 | 565.48 | 565.48 | 565.54 | 565.66 | 566.92 |
| 200,000 | | 569.26 | 567.10 | 567.04 | 566.98 | 567.16 | 567.22 | 567.22 | 567.28 | 569.08 |
| 210,000 | | 569.68 | 567.40 | 567.34 | 567.22 | 567.40 | 567.52 | 567.58 | 567.70 | 569.56 |
| 220,000 | | 570.04 | 567.70 | 567.64 | 567.58 | 567.70 | 567.82 | 567.82 | 567.94 | 569.74 |
| 255,000 | | 571.72* | 568.72 | 568.72 | 568.60 | 568.78 | 569.02 | 569.02 | 569.20 | 571.00 |
| | | | | | Black Rock Gage | | | | | |
| 150,000 | 565.12 | 565.42 | 565.06 | 565.00 | 565.00 | 565.12 | 565.06 | 565.12 | 565.12 | 565.00 |
| 200,000 | 567.28 | 567.28 | 566.62 | 566.62 | 566.44 | 566.62 | 566.62 | 566.62 | 566.62 | 566.80 |
| 210,000 | 567.71 | 567.70 | 566.92 | 566.86 | 566.74 | 566.92 | 566.98 | 566.98 | 566.92 | 567.16 |
| 220,000 | 568.12 | 568.09 | 567.16 | 567.10 | 566.98 | 567.16 | 567.22 | 567.16 | 567.16 | 567.40 |
| 255,000 | 569.76* | 569.59* | 568.06 | 568.06 | 567.94 | 568.18 | 568.24 | 568.18 | 568.30 | 568.54 |
| | | | | | Conners Island Gage | | | | | |
| 150,000 | 562.31 | 562.30 | 562.18 | 562.18 | 562.12 | 562.18 | 562.18 | 562.18 | 562.18 | 562.06 |
| 200,000 | 563.81 | 563.80 | 562.48 | 562.42 | 562.42 | 562.42 | 562.42 | 562.42 | 562.42 | 563.02 |
| 210,000 | 564.13 | 564.13 | 562.54 | 562.54 | 562.42 | 562.42 | 562.42 | 562.48 | 562.48 | 563.26 |
| 220,000 | 564.45 | 564.46 | 562.60 | 562.60 | 562.54 | 562.54 | 562.48 | 562.48 | 562.48 | 563.50 |
| 255,000 | 565.74* | 565.72* | 562.78 | 562.84 | 562.78 | 562.78 | 562.78 | 562.90 | 563.26 | 564.46 |

* 260,000 cfs

Table 2

Test Results, Deep-narrow Excavation Plans

| Outflow from Lake Erie, cfs | Water-surface Elevations in Feet, USLS 1935 Datum | | | | | | |
|---|---|---|---|---|---|---|---|
| | Prototype | Verification | Test 1 | Test 9 | Test 10 | Test 11 | Test 12 |
| | | | Buffalo Gage | | | | |
| 150,000 | 569.93 | 570.16 | 566.20 | 567.46 | 566.74 | 566.50 | 566.38 |
| 200,000 | 572.47 | 572.50 | 568.00 | 569.56 | 568.78 | 568.42 | 568.18 |
| 210,000 | 572.96 | 572.98 | 568.36 | 569.98 | 569.20 | 568.78 | 568.54 |
| 220,000 | 573.43 | 573.40 | 568.66 | 570.40 | 569.56 | 569.14 | 568.90 |
| 255,000 | 575.26* | 574.96* | 569.80 | 571.78 | 570.88 | 570.40 | 569.98 |
| | | | Peace Bridge Gage | | | | |
| 150,000 | | 567.10 | 565.42 | 565.54 | 565.42 | 565.42 | 565.48 |
| 200,000 | | 569.26 | 567.10 | 567.22 | 567.16 | 567.16 | 567.22 |
| 210,000 | | 569.68 | 567.40 | 567.70 | 567.52 | 567.52 | 567.58 |
| 220,000 | | 570.04 | 567.70 | 567.94 | 567.82 | 567.82 | 567.88 |
| 255,000 | | 571.72* | 568.72 | 569.20 | 569.02 | 569.02 | 568.96 |
| | | | Black Rock Gage | | | | |
| 150,000 | 565.12 | 565.42 | 565.06 | 565.12 | 565.06 | 565.06 | 565.06 |
| 200,000 | 567.28 | 567.28 | 566.62 | 566.56 | 566.56 | 566.56 | 566.56 |
| 210,000 | 567.71 | 567.70 | 566.92 | 566.86 | 566.80 | 566.80 | 566.86 |
| 220,000 | 568.12 | 568.09 | 567.16 | 567.10 | 567.10 | 567.10 | 567.16 |
| 255,000 | 569.76* | 569.59* | 568.06 | 568.18 | 566.18 | 568.12 | 568.06 |
| | | | Conners Island Gage | | | | |
| 150,000 | 562.31 | 562.30 | 562.18 | 562.24 | 562.18 | 562.24 | 562.18 |
| 200,000 | 563.81 | 563.80 | 562.48 | 562.48 | 562.48 | 562.42 | 562.48 |
| 210,000 | 564.13 | 564.13 | 562.54 | 562.54 | 562.48 | 562.48 | 562.54 |
| 220,000 | 564.45 | 564.46 | 562.60 | 562.54 | 562.54 | 562.54 | 562.60 |
| 255,000 | 565.74* | 565.72* | 562.78 | 563.38 | 562.84 | 562.72 | 562.78 |

* 260,000 cfs

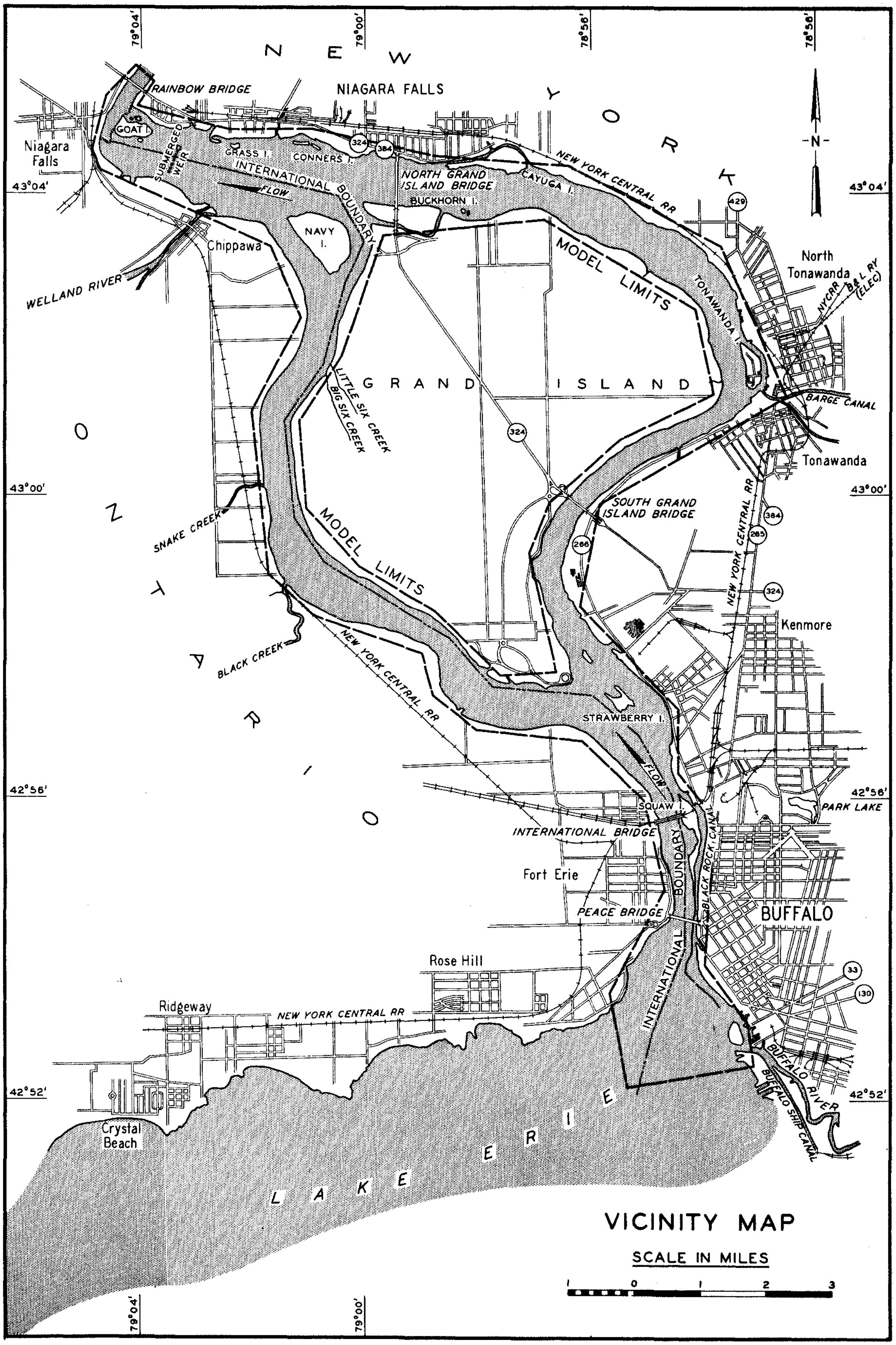
Table 3

Results of Tests of Regulating Structure

(All Tests Conducted with 1500-ft-wide Excavated Channel)

| Test No. | Outflow from Lake Erie cfs | Water-surface Elevations, ft Buffalo Gage | Water-surface Elevations, ft Conners Island Gage | Length of Structure Closed ft | Bottom El of Excavated Channel | Location* and Closed End of Structure |
|---|---|---|---|---|---|---|
| 13 | 90,000 | 572.9 | 562.0 | 2504 | 520.0 | (1) (a) |
| 14 | 90,000 | 572.9 | 562.0 | 2504 | 536.0 | (1) (a) |
| 15 | 90,000 | 572.9 | 562.0 | 2504 | 548.0 | (1) (a) |
| 16 | 90,000 | 572.9 | 562.0 | 3400 | 520.0 | (1) (b) |
| 17 | 90,000 | 572.9 | 562.0 | 1494 | 520.0 | (2) (a) |
| 18 | 90,000 | 572.9 | 562.0 | 1426 | 536.0 | (2) (a) |
| 19 | 90,000 | 572.9 | 562.0 | 1316 | 548.0 | (2) (a) |
| 20 | 90,000 | 572.9 | 562.0 | 1400 | 520.0 | (2) (b) |
| 21 | 90,000 | 571.9 | 562.0 | 2340 | 520.0 | (1) (a) |
| 22 | 90,000 | 571.9 | 562.0 | 2335 | 536.0 | (1) (a) |
| 23 | 90,000 | 571.9 | 562.0 | 2327 | 548.0 | (1) (a) |
| 24 | 90,000 | 571.9 | 562.0 | 1477 | 520.0 | (2) (a) |
| 25 | 90,000 | 571.9 | 562.0 | 1412 | 536.0 | (2) (a) |
| 26 | 90,000 | 571.9 | 562.0 | 1286 | 548.0 | (2) (a) |
| 27 | 90,000 | 571.9 | 562.0 | 1384 | 520.0 | (2) (b) |
| 28 | 140,000 | 572.9 | 564.22 | 2277 | 520.0 | (1) (a) |
| 29 | 140,000 | 572.9 | 564.22 | 1395 | 520.0 | (2) (a) |
| 30 | 140,000 | 572.9 | 564.22 | 1306 | 520.0 | (2) (b) |
| 31 | 200,000 | 569.6 | 562.48 | 1900 | 520.0 | (1) (a) |
| 32 | 200,000 | 569.6 | 562.48 | 1120 | 520.0 | (2) (a) |
| 33 | 220,000 | 569.6 | 562.54 | 1717 | 520.0 | (1) (a) |
| 34 | 220,000 | 569.6 | 562.54 | 2806 | 520.0 | (1) (b) |
| 35 | 220,000 | 569.6 | 562.54 | 980 | 520.0 | (2) (a) |

* Location.
(1) Bird Island.
(2) Peace Bridge.
(a) Closed from American shore.
(b) Closed from Canadian shore.



NEW YORK
ONTARIO
NIAGARA FALLS
Niagara Falls
RAINBOW BRIDGE
GOAT I.
SUBMERGED WEIR
GRASS I.
CONNERS I.
INTERNATIONAL BOUNDARY
FLOW
NORTH GRAND ISLAND BRIDGE
CAYUGA I.
BUCKHORN I.
NAVY I.
NEW YORK CENTRAL RR
Chippawa
WELLAND RIVER
MODEL LIMITS
TONAWANDA I.
North Tonawanda
NYCRR
B&L RY (ELEC)
BARGE CANAL
GRAND ISLAND
LITTLE SIX CREEK
BIG SIX CREEK
Tonawanda
SOUTH GRAND ISLAND BRIDGE
SNAKE CREEK
BLACK CREEK
Kenmore
STRAWBERRY I.
SQUAW I.
INTERNATIONAL BRIDGE
PARK LAKE
Fort Erie
BLACK ROCK CANAL
PEACE BRIDGE
BUFFALO
Rose Hill
Ridgeway
Crystal Beach
BUFFALO RIVER
BUFFALO SHIP CANAL
LAKE ERIE
79°04'
79°00'
78°56'
43°04'
43°00'
42°56'
42°52'
324
384
429
266
285
33
130
N
VICINITY MAP
SCALE IN MILES
1 0 1 2 3


PLATE 1

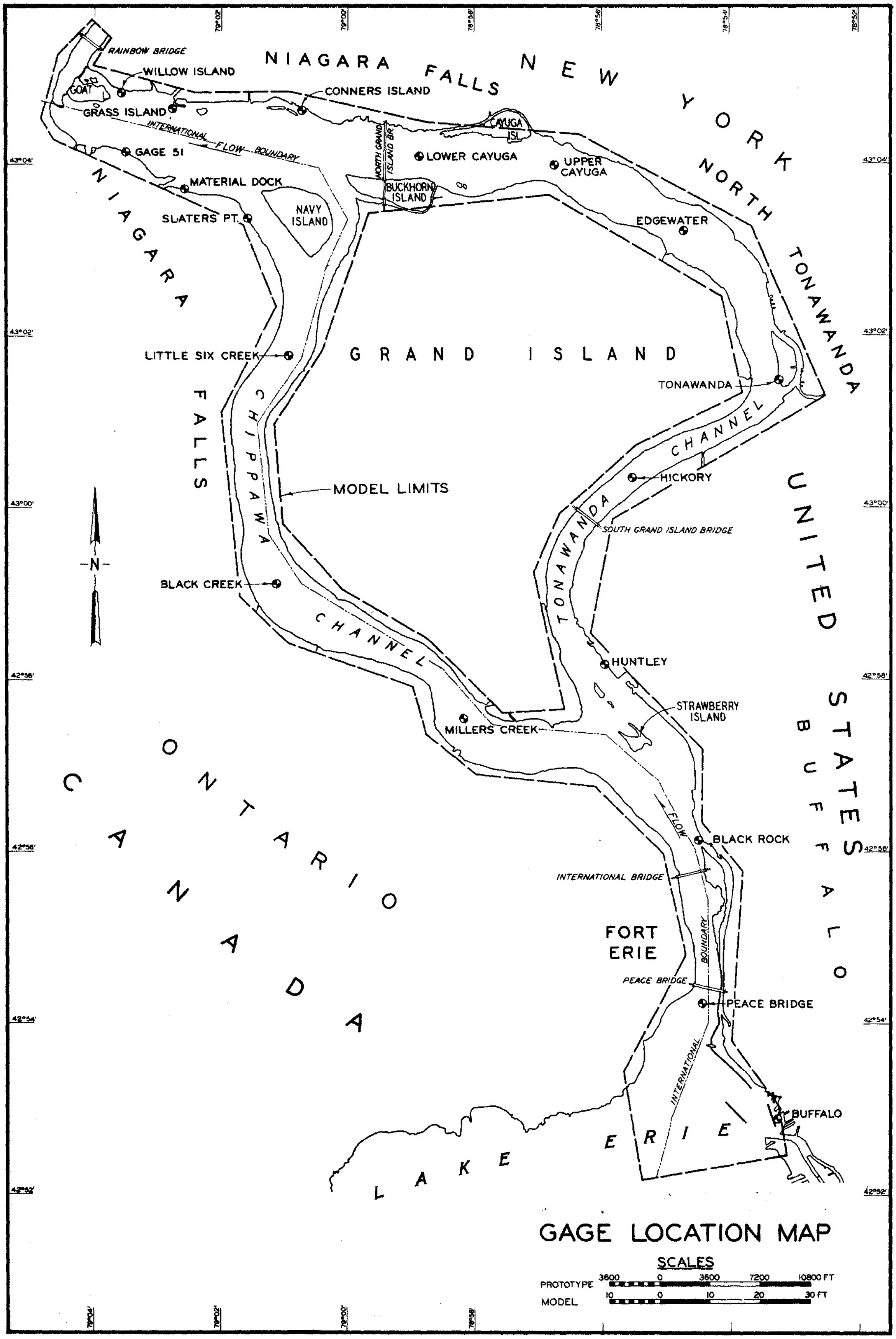
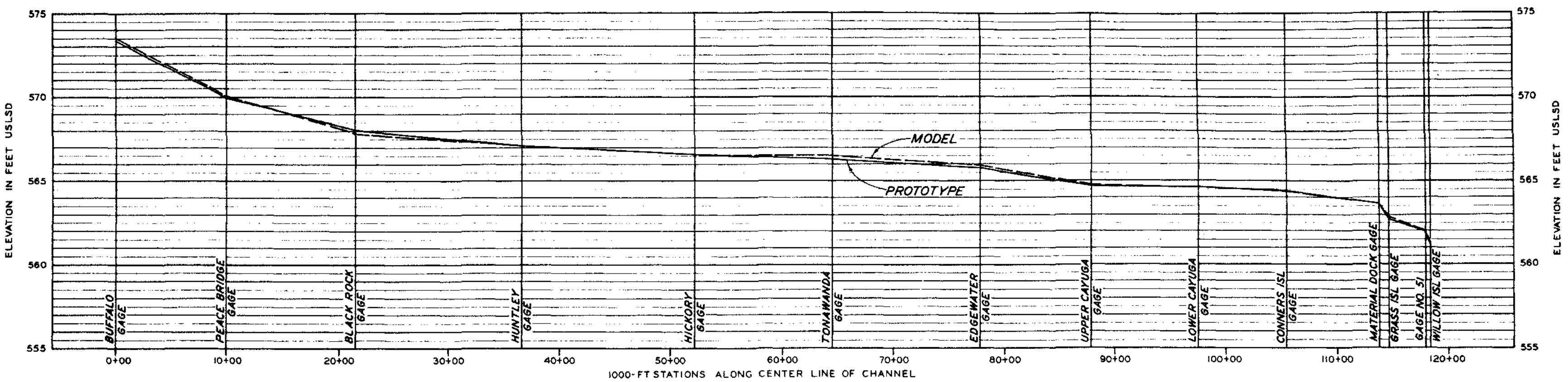
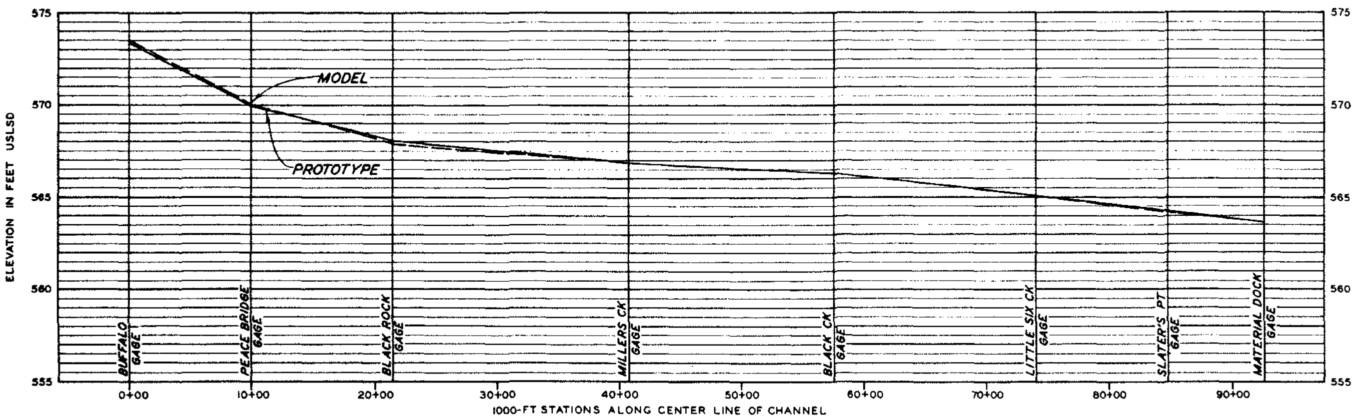

RAINBOW BRIDGE
WILLOW ISLAND
GOAT
GRASS ISLAND
CONNERS ISLAND
NIAGARA FALLS
NEW YORK
CAYUGA ISL.
INTERNATIONAL FLOW BOUNDARY
GAGE 51
NORTH GRAND ISLAND BR.
LOWER CAYUGA
UPPER CAYUGA
NORTH TONAWANDA
MATERIAL DOCK
BUCKHORN ISLAND
NAVY ISLAND
SLATERS PT.
EDGEWATER
NIAGARA
LITTLE SIX CREEK
GRAND ISLAND
TONAWANDA
FALLS
CHIPPAWA
CHANNEL
MODEL LIMITS
HICKORY
UNITED STATES
SOUTH GRAND ISLAND BRIDGE
TONAWANDA
BLACK CREEK
HUNTLEY
STRAWBERRY ISLAND
MILLERS CREEK
BUFFALO
ONTARIO
CANADA
FLOW
BLACK ROCK
INTERNATIONAL BRIDGE
FORT ERIE
BOUNDARY
PEACE BRIDGE
INTERNATIONAL
LAKE ERIE
N
79°04'
79°02'
79°00'
78°58'
78°56'
78°54'
78°52'
43°04'
43°02'
43°00'
42°58'
42°56'
42°54'
42°52'
GAGE LOCATION MAP
SCALES
PROTOTYPE 3600 0 3600 7200 10800 FT
MODEL 10 0 10 20 30 FT

PLATE 2

PLATE 3




AMERICAN CHANNEL



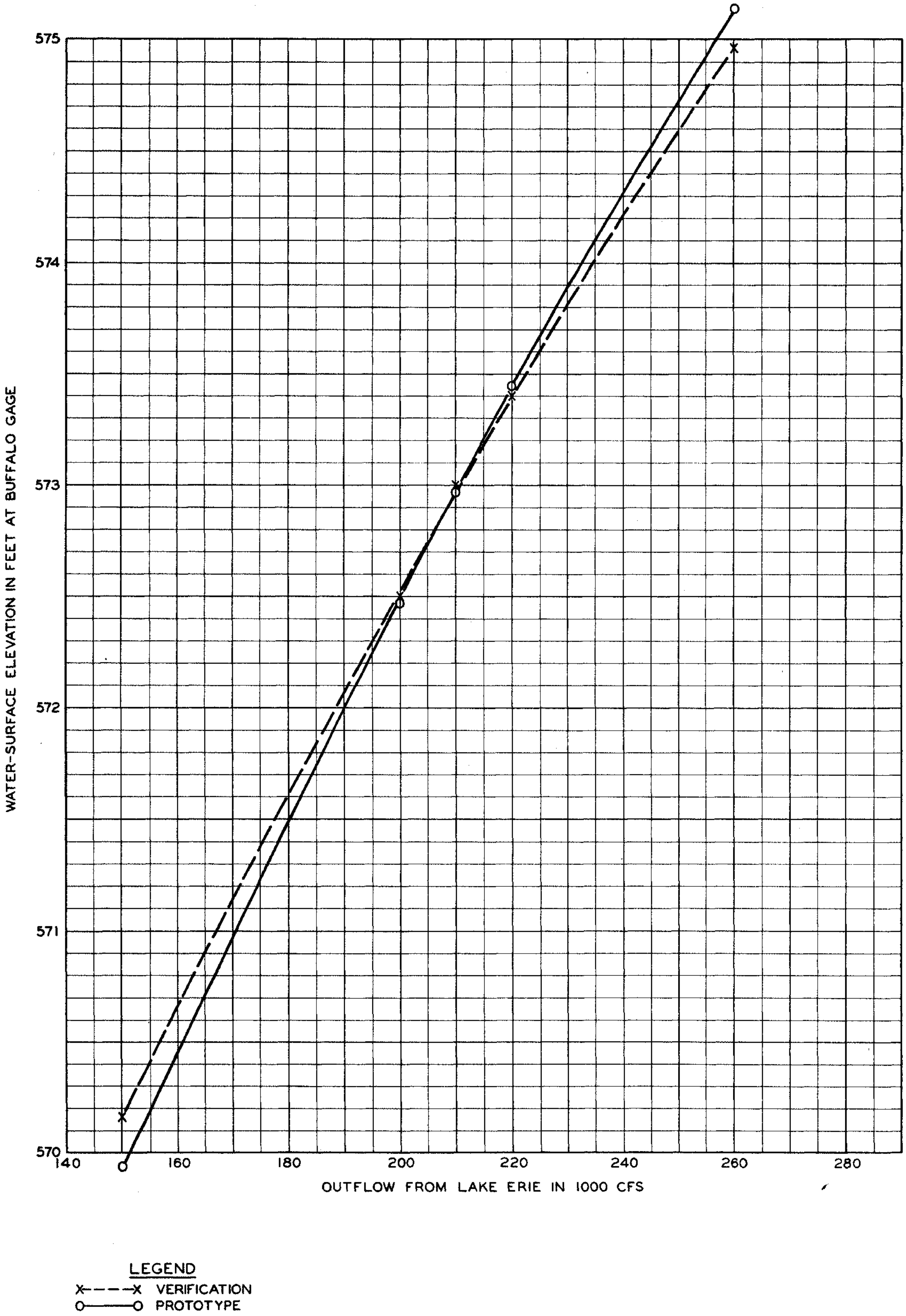

CANADIAN CHANNEL

## TEST CONDITIONS

| | |
|---|---|
| **INFLOW** | |
| NIAGARA RIVER | 223,488 CFS |
| **DIVERSIONS** | |
| SCHOELLKOPF | 23,351 CFS |
| ADAMS STATION | 8,610 CFS |
| QUEENSTON | 15,258 CFS |
| TORONTO | 13,915 CFS |
| CANADIAN NIAGARA | 9,728 CFS |
| ONTARIO | 10,093 CFS |
| **OUTFLOW** | |
| FALLS | 142,553 CFS |

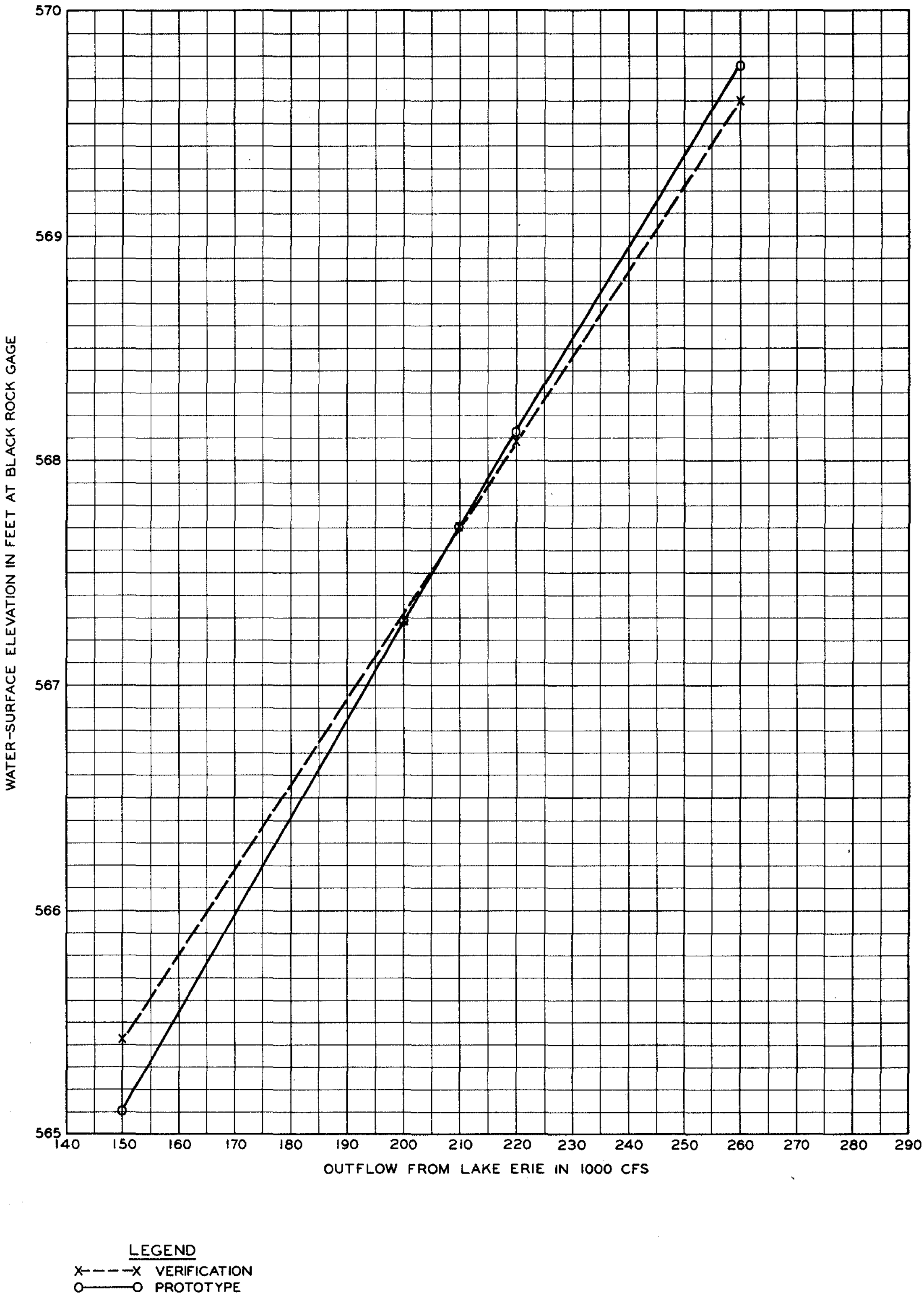
NOTE: GAGE LOCATIONS SHOWN ON PLATE 2.

# WATER – SURFACE PROFILES
## VERIFICATION TEST

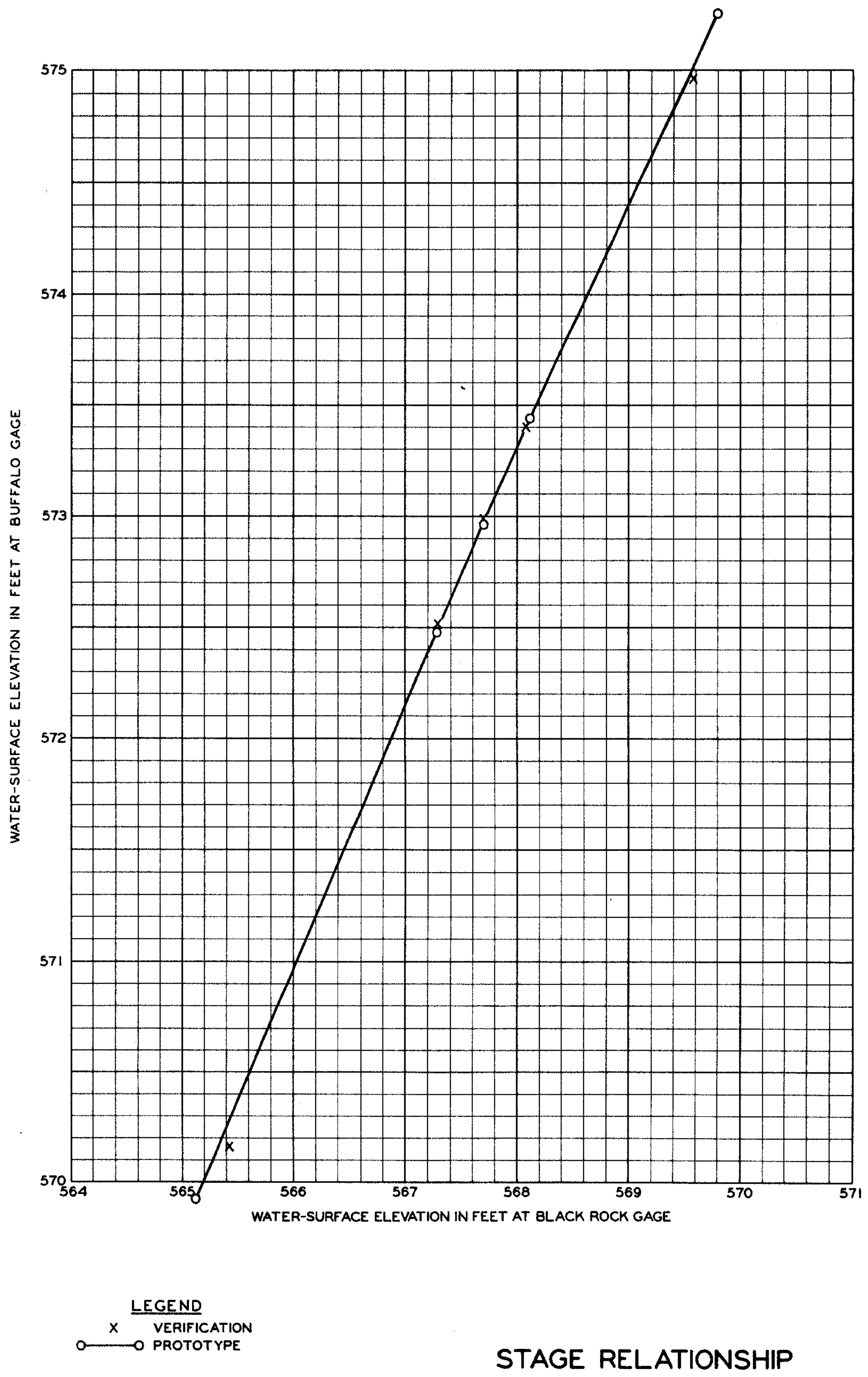



STAGE-DISCHARGE RELATIONSHIP
BUFFALO GAGE

PLATE 4



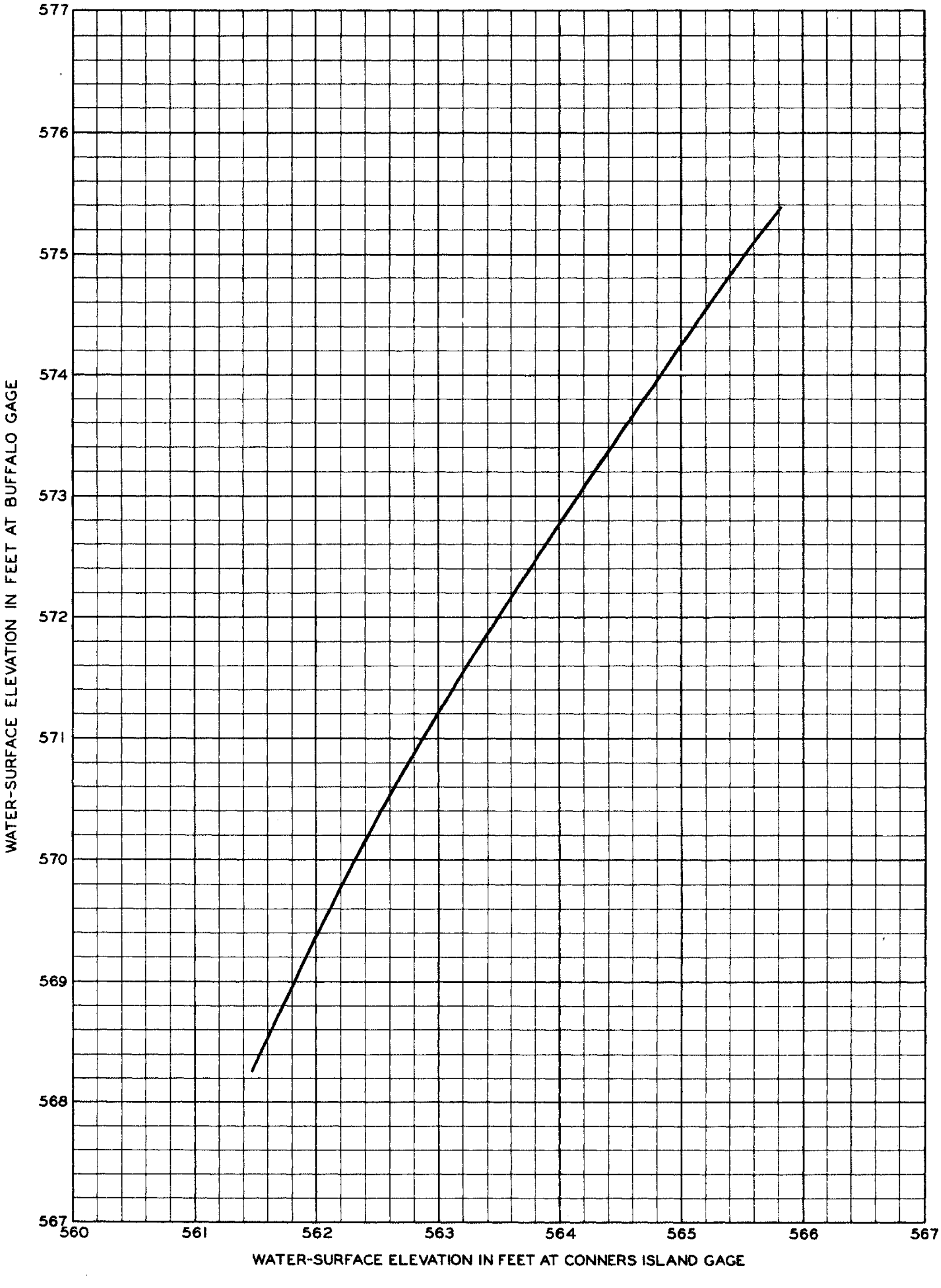

STAGE-DISCHARGE RELATIONSHIP
BLACK ROCK GAGE



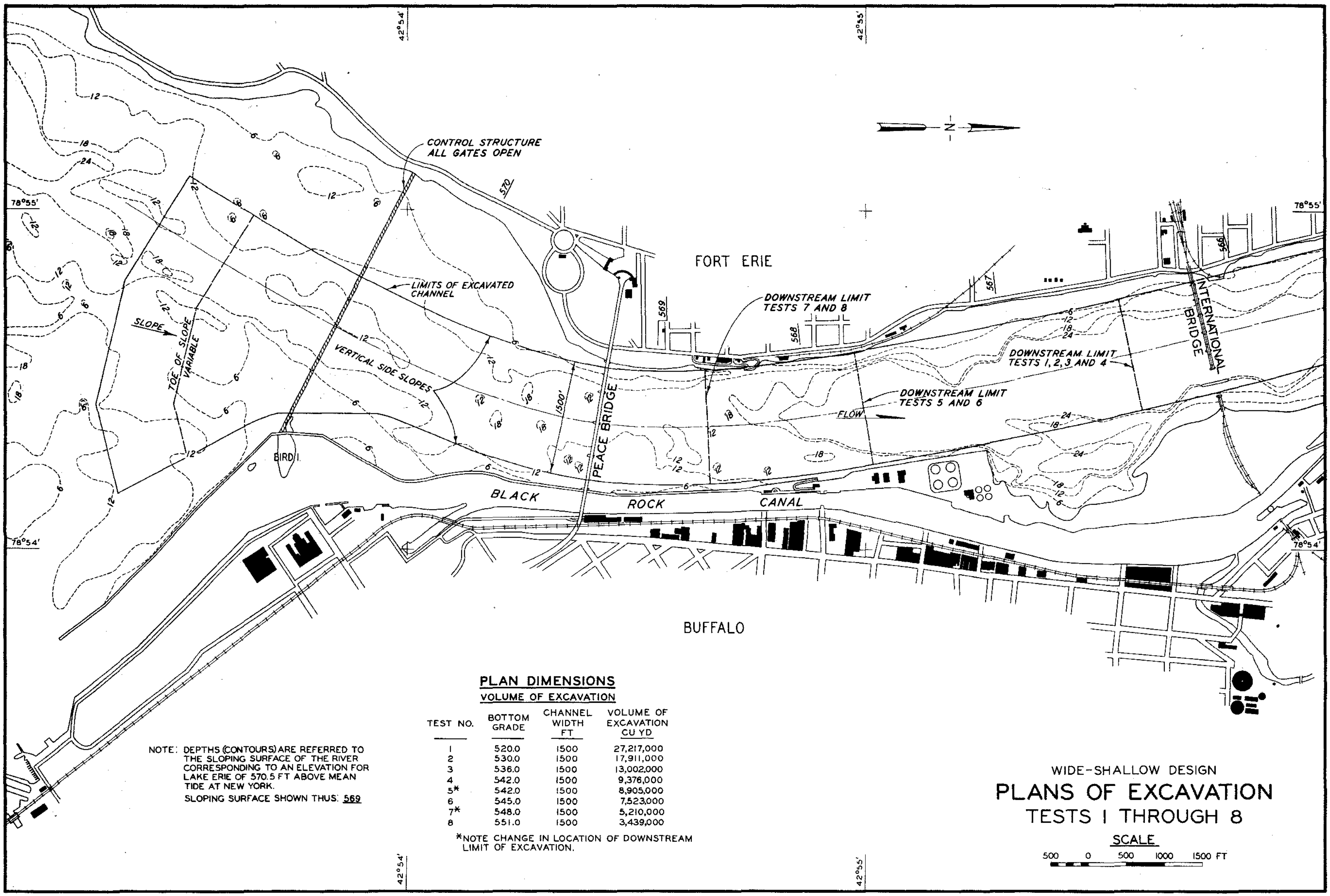

## STAGE RELATIONSHIP

BUFFALO GAGE VS BLACK ROCK GAGE

PLATE 6




STAGE RELATIONSHIP
BUFFALO GAGE VS CONNERS ISLAND GAGE




## PLAN DIMENSIONS

### VOLUME OF EXCAVATION

| TEST NO. | BOTTOM GRADE | CHANNEL WIDTH FT | VOLUME OF EXCAVATION CU YD |
|---|---|---|---|
| 1 | 520.0 | 1500 | 27,217,000 |
| 2 | 530.0 | 1500 | 17,911,000 |
| 3 | 536.0 | 1500 | 13,002,000 |
| 4 | 542.0 | 1500 | 9,376,000 |
| 5* | 542.0 | 1500 | 8,905,000 |
| 6 | 545.0 | 1500 | 7,523,000 |
| 7* | 548.0 | 1500 | 5,210,000 |
| 8 | 551.0 | 1500 | 3,439,000 |

*NOTE CHANGE IN LOCATION OF DOWNSTREAM LIMIT OF EXCAVATION.

NOTE: DEPTHS (CONTOURS) ARE REFERRED TO THE SLOPING SURFACE OF THE RIVER CORRESPONDING TO AN ELEVATION FOR LAKE ERIE OF 570.5 FT ABOVE MEAN TIDE AT NEW YORK.

SLOPING SURFACE SHOWN THUS: 569

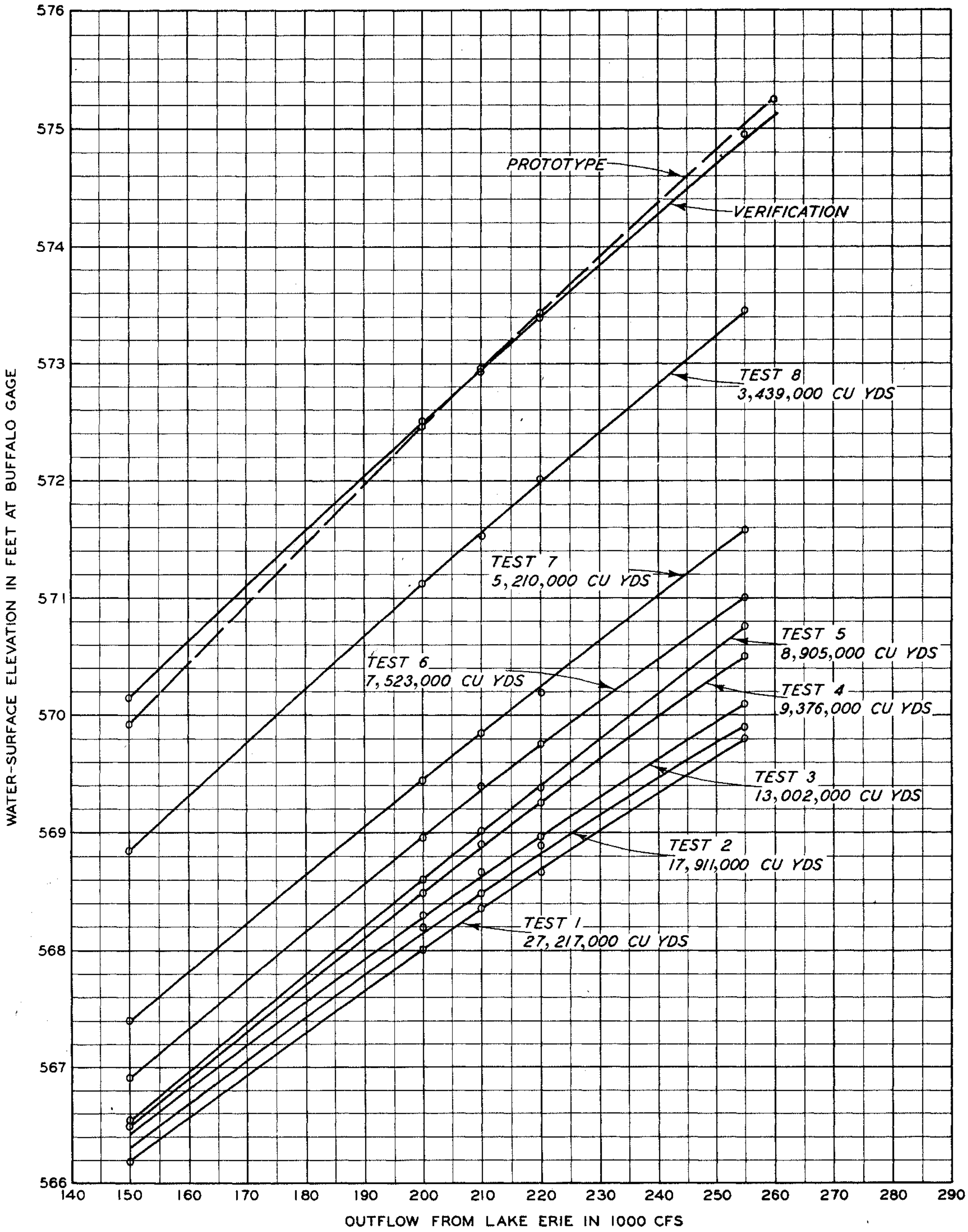
WIDE-SHALLOW DESIGN

# PLANS OF EXCAVATION

## TESTS 1 THROUGH 8

SCALE

500 0 500 1000 1500 FT

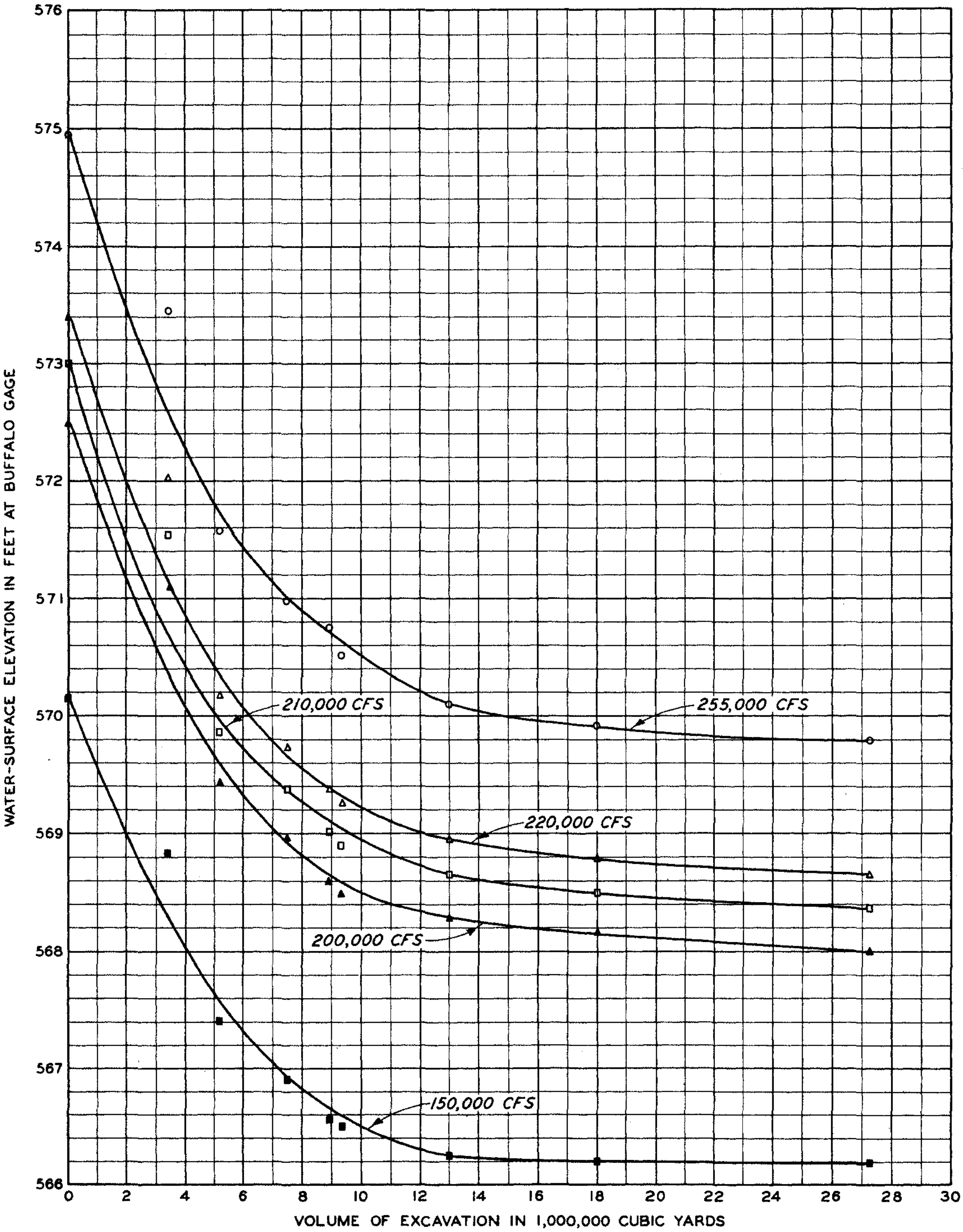



WIDE-SHALLOW EXCAVATION PLANS

## WATER-SURFACE ELEVATION

VS

## OUTFLOW FROM LAKE ERIE



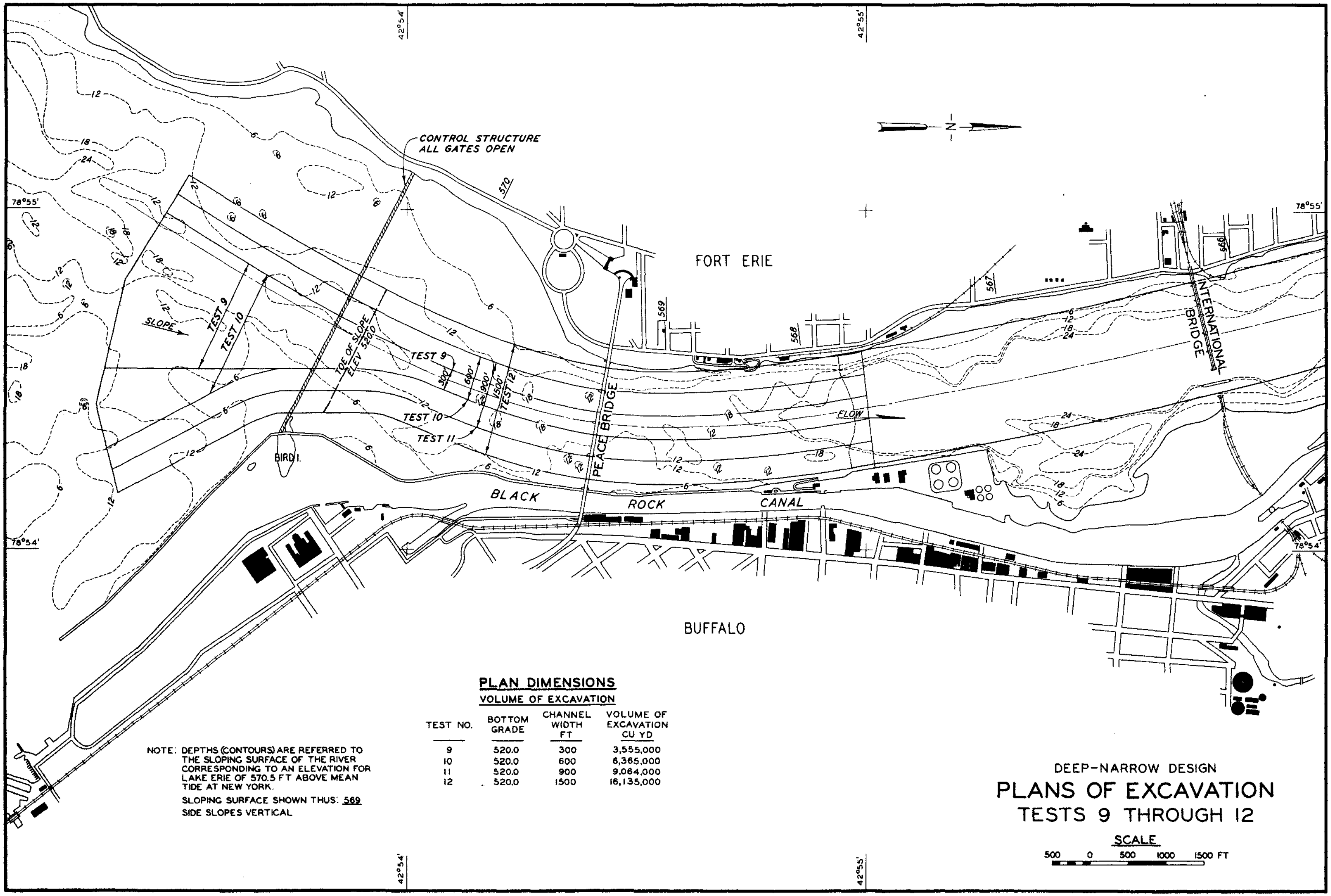

WIDE-SHALLOW EXCAVATION PLANS

# WATER-SURFACE ELEVATION

VS

# VOLUME OF EXCAVATION

PLATE 10




## PLAN DIMENSIONS

VOLUME OF EXCAVATION

| TEST NO. | BOTTOM GRADE | CHANNEL WIDTH FT | VOLUME OF EXCAVATION CU YD |
|---|---|---|---|
| 9 | 520.0 | 300 | 3,555,000 |
| 10 | 520.0 | 600 | 6,365,000 |
| 11 | 520.0 | 900 | 9,064,000 |
| 12 | 520.0 | 1500 | 16,135,000 |

NOTE: DEPTHS (CONTOURS) ARE REFERRED TO THE SLOPING SURFACE OF THE RIVER CORRESPONDING TO AN ELEVATION FOR LAKE ERIE OF 570.5 FT ABOVE MEAN TIDE AT NEW YORK.

SLOPING SURFACE SHOWN THUS: 569

SIDE SLOPES VERTICAL

DEEP-NARROW DESIGN

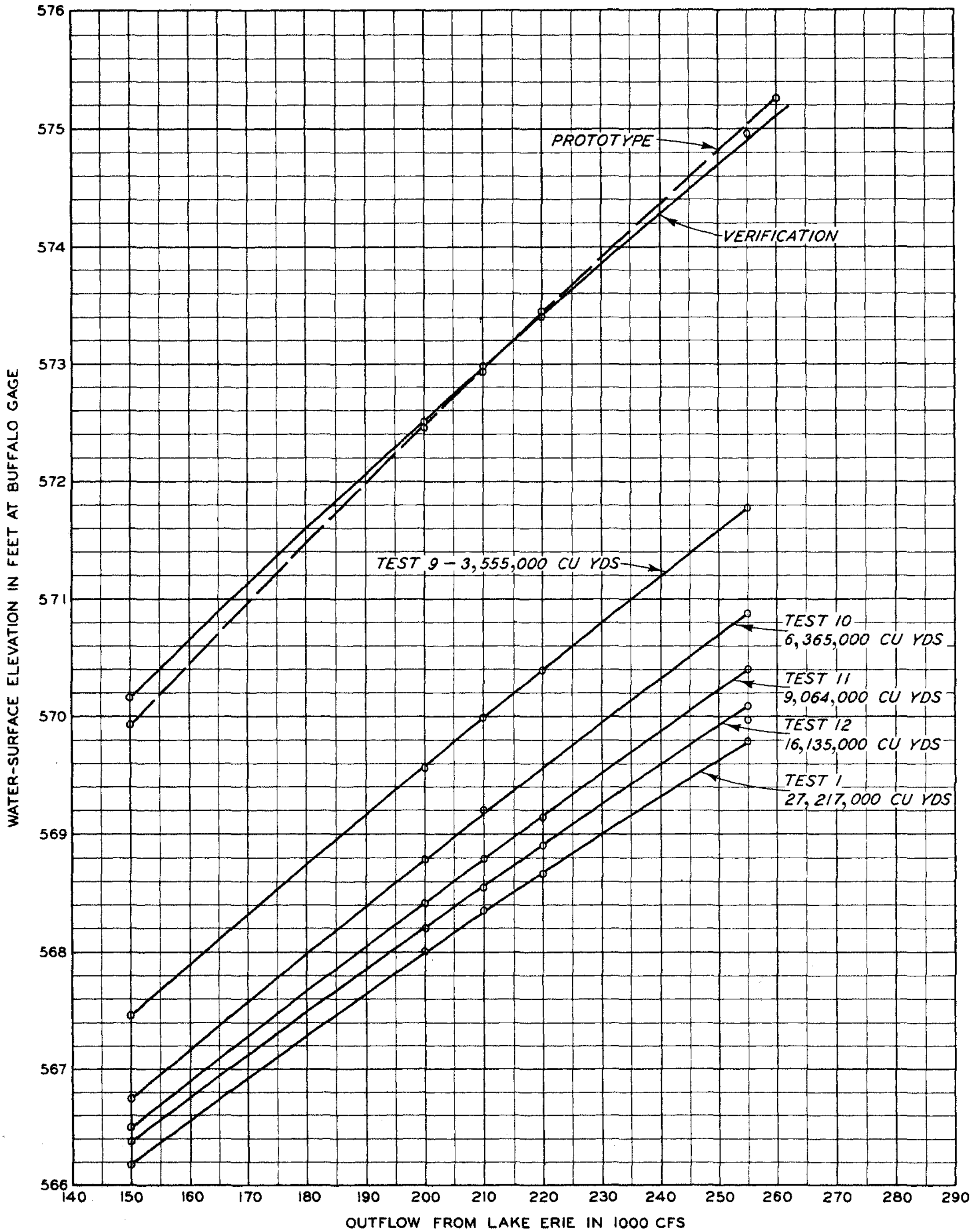
# PLANS OF EXCAVATION

## TESTS 9 THROUGH 12

SCALE

500 0 500 1000 1500 FT

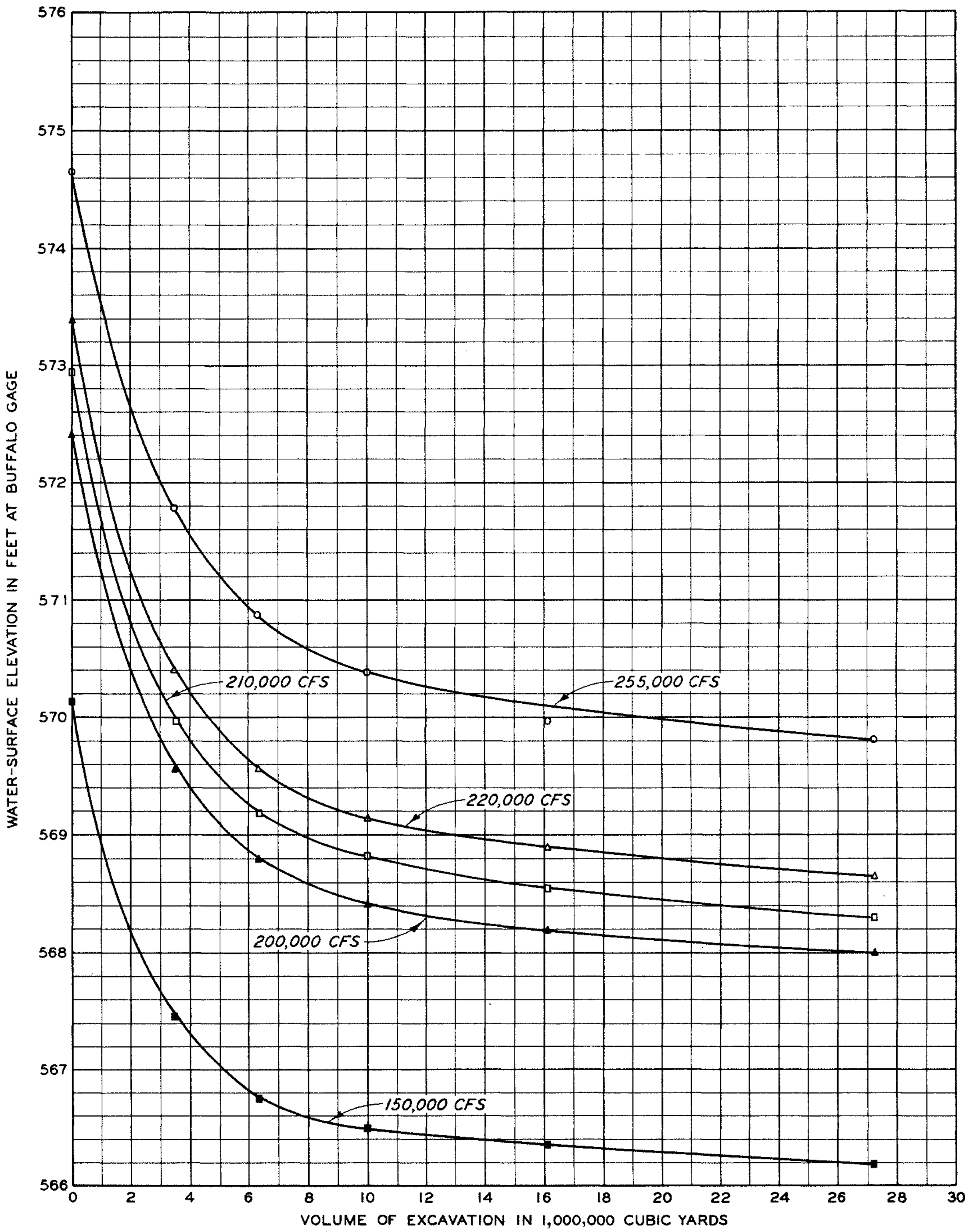
PLATE 11




DEEP-NARROW EXCAVATION PLANS

## WATER-SURFACE ELEVATION
VS
## OUTFLOW FROM LAKE ERIE

PLATE 12



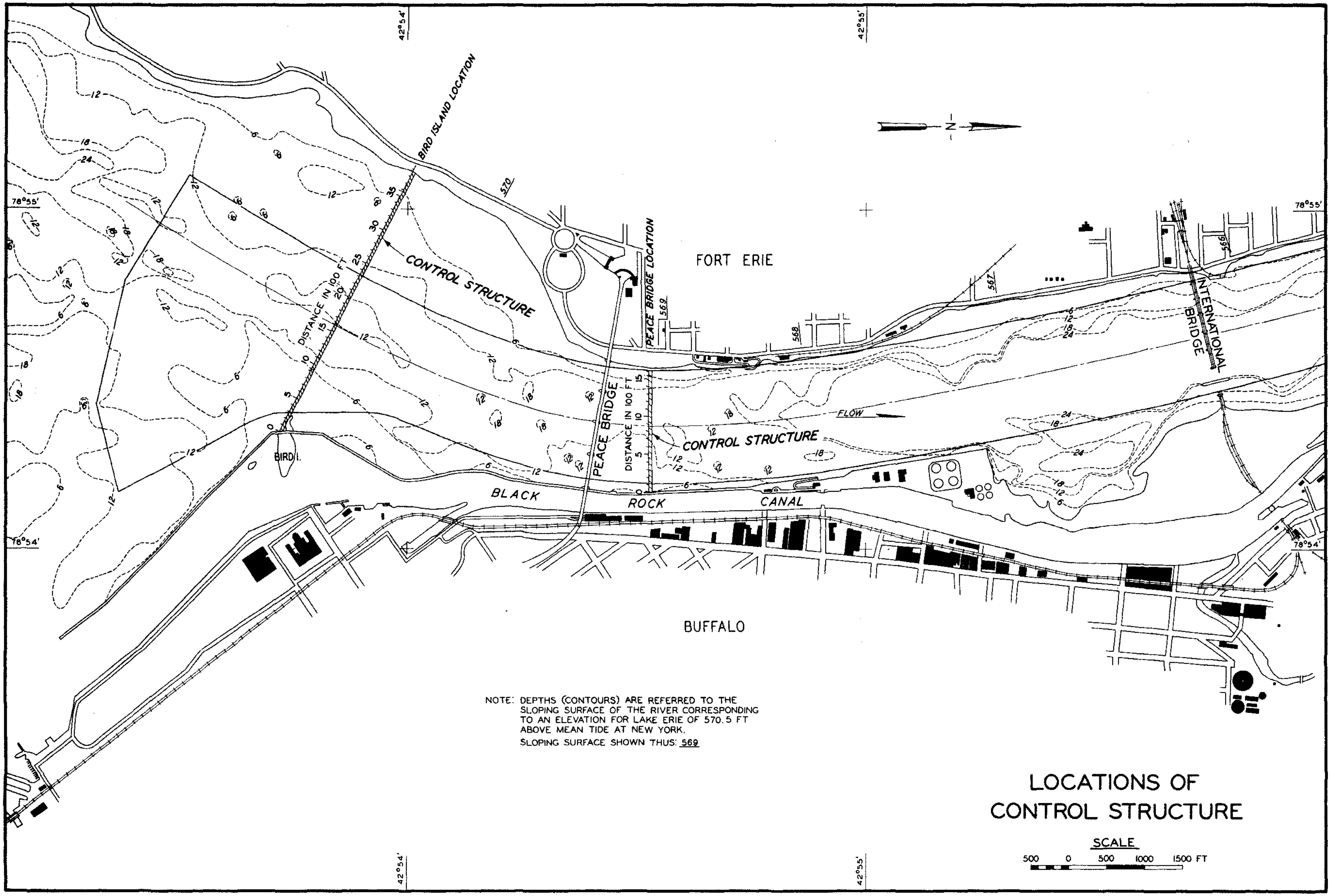

DEEP - NARROW EXCAVATION PLANS

# WATER-SURFACE ELEVATION

VS

# VOLUME OF EXCAVATION

PLATE 14



FORT ERIE
BUFFALO
BLACK ROCK CANAL
BIRD ISLAND LOCATION
PEACE BRIDGE LOCATION
PEACE BRIDGE
INTERNATIONAL BRIDGE
CONTROL STRUCTURE
CONTROL STRUCTURE
DISTANCE IN 100 FT
DISTANCE IN 100 FT
BIRD I.
FLOW
N
42°54'
42°55'
78°55'
78°54'
570
569
568
567
NOTE: DEPTHS (CONTOURS) ARE REFERRED TO THE SLOPING SURFACE OF THE RIVER CORRESPONDING TO AN ELEVATION FOR LAKE ERIE OF 570.5 FT ABOVE MEAN TIDE AT NEW YORK.
SLOPING SURFACE SHOWN THUS: 569
LOCATIONS OF CONTROL STRUCTURE
SCALE
500 0 500 1000 1500 FT